20030128400

AD-A204 149

REPRODUCTION QUALITY NOTICE

This document is the best quality available. The copy furnished to DTIC contained pages that may have the following quality problems:

- Pages smaller or larger than normal.
- Pages with background color or light colored printing.
- Pages with small type or poor printing; and or
- Pages with continuous tone material or color photographs.

Due to various output media available these conditions may or may not cause poor legibility in the microfiche or hardcopy output you receive.

☐ If this block is checked, the copy furnished to DTIC contained pages with color printing, that when reproduced in Black and White, may change detail of the original copy.

This document contains blank pages that were not filmed

Best Available Copy

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY 2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	3. DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release distribution unlimited
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) NATICK/TR-89/005
6a. NAME OF PERFORMING ORGANIZATION Ro-Search, Inc. 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION U.S. Army Natick RD&E Center
6c. ADDRESS (City, State, and ZIP Code) Waynesville, NC 28736	7b. ADDRESS (City, State, and ZIP Code) Individual Protection Directorate STRNC-IUC Natick, MA 01760-5019
8a. NAME OF FUNDING / SPONSORING ORGANIZATION 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER DAAK60-87-C-0042
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. | PROJECT NO. 7300029 124000 | TASK NO. | WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Development of an Integrated, Lightweight Combat Boot - Phase I

12. PERSONAL AUTHOR(S)
Horace Auberry

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM Jun 87 TO Mar 88	May 1988	33

16. SUPPLEMENTARY NOTATION

Protective clothing, (...)

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	FIRE RESISTANT MATERIALS, SKID RESISTANCE, FOOTWEAR,
			TEMPERATE REGIONS, WATERPROOFING, WARFARE,
			WEIGHT REDUCTION, LIGHTWEIGHT, INSULATION,

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report describes the development of an integrated, lightweight, waterproof, flame-resistant combat boot suitable for all-season wear in temperate climates. This boot, designated Model SBN-88, also includes a puncture resistant, mud shedding traction sole and a detachable chemical threat resistant bootie. This boot was developed under Phase I of the Small Business Innovation Research program and the report lists the objectives that were met and describes the future design changes needed to meet the objectives that were not met.

Keywords: ...

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Charles A. Smith	22b. TELEPHONE (Include Area Code) 508-651-4548 | 22c. OFFICE SYMBOL STRNC-IUC

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

PREFACE

The development of an integrated, lightweight combat boot, Phase 1, described in this report was performed by Ro-Search, Inc., Waynesville, N. C., during the period 29JUN87 and 1MAR88 under U. S. Army Natick contract DAAK60-87-C-0042. The Project Officer was Charles Smith.

Cambrelle, Gore-Tex, Kevlar, Poron, Surlyn, Texon, Velcro, and Zepel are registered trade names. Citation of trade names in this report does not constitute an official endorsement or approval of the use of such items.

Table of Contents

L : Of Illustrations

DEVELOPMENT OF AN INTEGRATED, LIGHTWEIGHT COMBAT BOOT - PHASE 1

I. Purpose and Product: The purpose of this project was to develop a lightweight, waterproof, flame resistant, combat boot, designated model SBN-88, suitable for all-season wear in temperate climates, with puncture-resistant, traction, mud-shedding sole and detachable, chemical-threat-resistant bootie.

Table 1, Material Specifications, and Table 2, Summary of Features, more fully describe the boot. See also Figures 1 and 2.

II. Technical Objectives Met:

1. Weight: A pair of size 9R model SBN-88 boots were developed that weighed 1465 grams (3.23 pounds) compared to 1862 grams (4.11 pounds) for the present combat boot.

Ro-Search has added many special features and still reduced the weight dramatically. Table 3, Weight Comparison, details exactly how this reduction was accomplished through design and substitution of materials for the sole, upper, shank and insole. Except for the aluminum and brass in the closure system, there is no metal in the boot. Even the heel seat tacks have been eliminated.

2. Flame resistance: A major part of the decreased weight and increased comfort of model SBN-88 comes from the substitution of fabric for leather in the upper, and yet this boot is even

more flame resistant than the current all-leather item. This increased resistance is possible because the outer fabric is a combination of Kevlar and PBI. A brochure, entitled Celanese/PBI, describing this material appears as Appendix A.

The polyurethane in the sole is flammable but it is protected by the nitrile rubber tread sole, except for a 1/4" wide strip around the extension adjoining the upper.

3. Waterproof: All leather parts conform to treatment A/B of MIL-B-3122F, which requires a significant resistance to water penetration and water absorption. However, the fabric portion is not water resistant and the needle holes are open.

Waterproofness is obtained by the inner lining consisting of tricot/Gore-Tex/Cambrelle with Gore-Tex tape sealed seams. Liquids penetrating the outer materials are stopped by the Gore-Tex barrier.

4. Chemical Agent Resistance: The boot itself is somewhat resistant to chemical agents due to the several layers of material, the sealed seams and the relatively thick rubber/polyurethane sole.

Significant additional resistance is provided through the detachable bootie. The bootie material consists of a layer of nylon against the foot for comfort and ease of entry, followed in order by cotton jersey, carbon spheres, cotton jersey, Gore-Tex and, finally, nylon tricot. The seams are sealed with

TABLE 1

MATERIAL SPECIFICATIONS FOR BOOT

COMPONENT	DESCRIPTION
Upper leather	Conforms to Treatment A/B of MIL-L-3122, mellow temper, full grain as for the present combat boot
Collar leather	2.5 oz glove leather as used in the present combat boot
Kevlar/PBI	8.5 oz 40/60 PBI/Kevlar 29, piece-dyed black, rip-stop weave, 46 ends X 36 picks. Zepel treated for water repellency
Upper lining	A three layer laminate of 4.5 oz. 66/6 nylon, Polytetrafluro ethylene membrane and 1.8 oz. 66 nylon knit
Seam sealing tape	A laminate of 1.8 oz. 66 nylon knit, polytetrafluro ethylene and thermoplastic adhesive
Binding tape	Nylon tape conforming to MIL-T-5038 as used in the Hot Weather boot except black in color
Velcro hook & loop	Velcro hook is 65 hooks per square inch in woven nylon Velcro loop is 1,000 loops per square inch woven nylon tape
Back stay	1" nylon webbing as used in the Hot Weather boot
Speed loops assembly	Consisting of speed loop and tubular rivet, both nylon coated brass
Eyelets	Roller coated, enameled aluminum, commercial size destination AA
Leather insole	3 iron insole conforming to K-K-I-570 as used in the all-leather boot except for thickness
Kevlar puncture-resistant insole	4.8 ounce 1420 X 1420 pararamid yarn (Style 500 Kevlar 49)

TABLE 1 cont'd

COMPONENT	DESCRIPTION
Texon bottom insole	3 iron neoprene impregnated cellulose substrate (480 Texon)
Back seam tape	1/2" wide cotton as used in the present combat boot
Box toe material	.056" polystyrene/Surlyn(R)/polystyrene as used in the present combat boot
Thread	Size E, nylon coated, nonwicking as used in the present combat boot
Fiberglass shank	7/8" wide made of glass fibers, impregnated with vinyl ester resins and encased in a plastic sleeve
Polyurethane midsole	Polyester polyurethane, .40 - .50 molded density (g/cc), Tensile strength 450, Hardness Shore A 50-55
Nitrile rubber thread sole	Conforms to the heel rubber requirements for the present combat boot as detailed in MIL-B-44152
Cushion insole	1/8" thick Poron(R), polyurethane foam on 1 iron Texon(R) as approved by alternate use in the present combat boot (Poron 4810)
Bootie fabric	A sandwich of cotton single jersey knit/.4 mm, carbon sphere absorbers/cotton single jersey knit. The jersey knit is 2.95 oz per square yard. The spherical absorber is 2.36 oz. per square yard. A layer of Gore-Tex(R) nylon knit as used in the lining is additionally laminated to the jersey knit sandwich.

TABLE 2 Summary of Features and Cost Comparison, Developmental and Present Boots

FEATURE	INSTEAD OF:	DESIRABLE CHARACTERISTICS	COST COMPARISON (1)
Expanded PU/Nitrile rubber outsole	Solid Nitrile rubber	Lightweight, cushioned support	+ $ .71 (2)
Modified Panama tread design	Traction outsole	Lightweight, flexibility, skid resistance, mud shedding	- .25
Fiberglass shank	Steel	Lightweight, permanently fixed, hazard resistance, chemical and corrosion resistance	- .07
No tacks, nails or staples	Metallic heel seat tacks, heel nails and staples	Weight, hazard resistance	- .08
Kevlar puncture-resistant insole layer	Stainless steel	Lightweight, flexibility, hazard resistance	+ .28 (3)
Texon bottom layer insole	Leather	Cost, improved puncture resistance	- .13 (3)
Cambrelle/Gore-Tex (R) lining	No lining	Comfort, water resistance, foot health	+ 6.51
Kevlar/PBI quarter and gusset	Leather	Lightweight, fire resistant, puncture resistance	- 1.07
Chemical resistant bootie	No bootie	Chemical agent resistance	+ 19.09

(1) Direct labor and material only, (-) cost advantage, (+) cost disadvantage. No consideration given for overhead, machine cost, etc.
(2) Compared to a DMS unit sole construction rather than with the separately molded nailed on heel as in the present boot.
(3) Compared with the Hot Weather boot puncture-resistant insole.

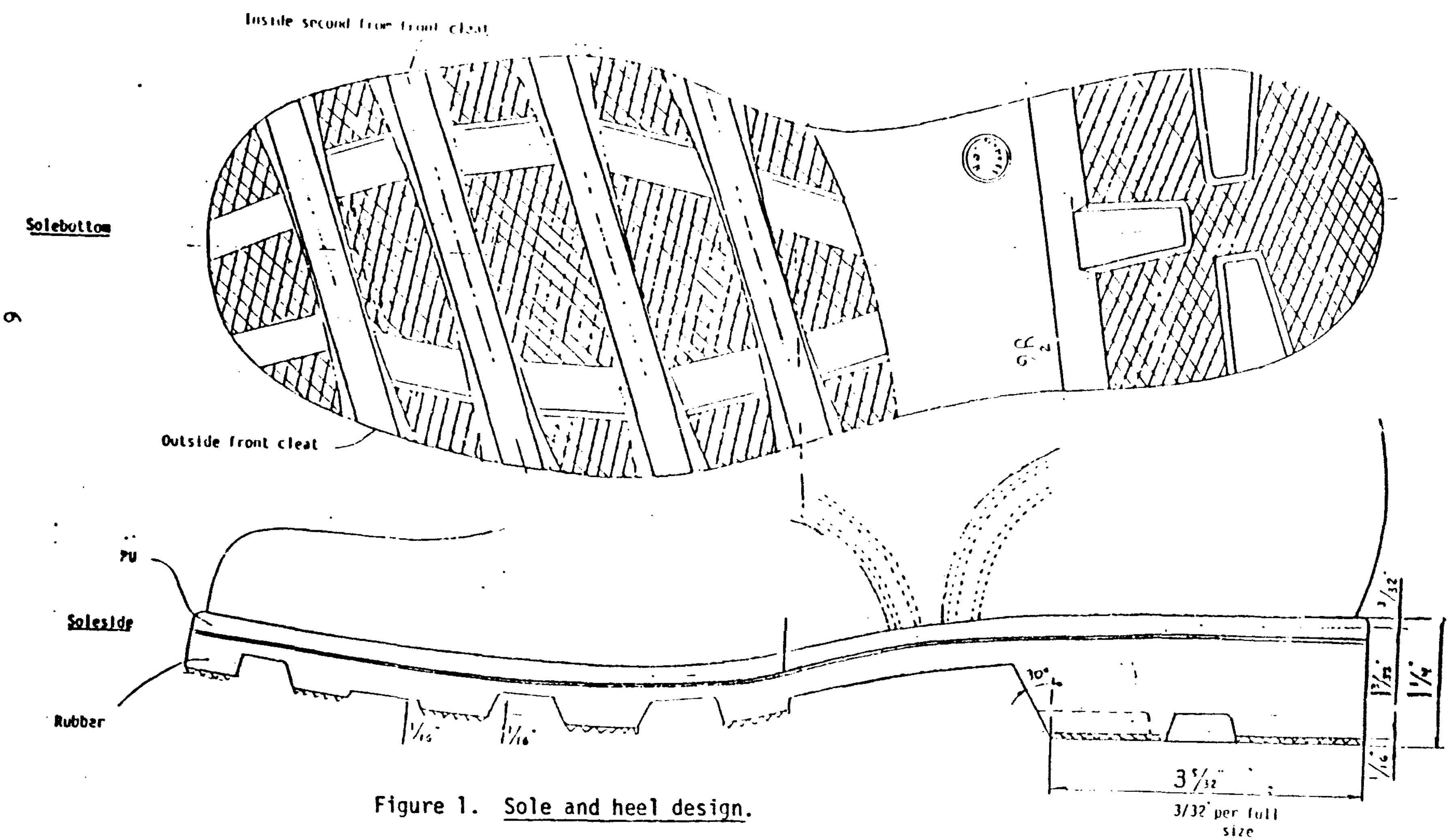


Figure 1. Sole and heel design.

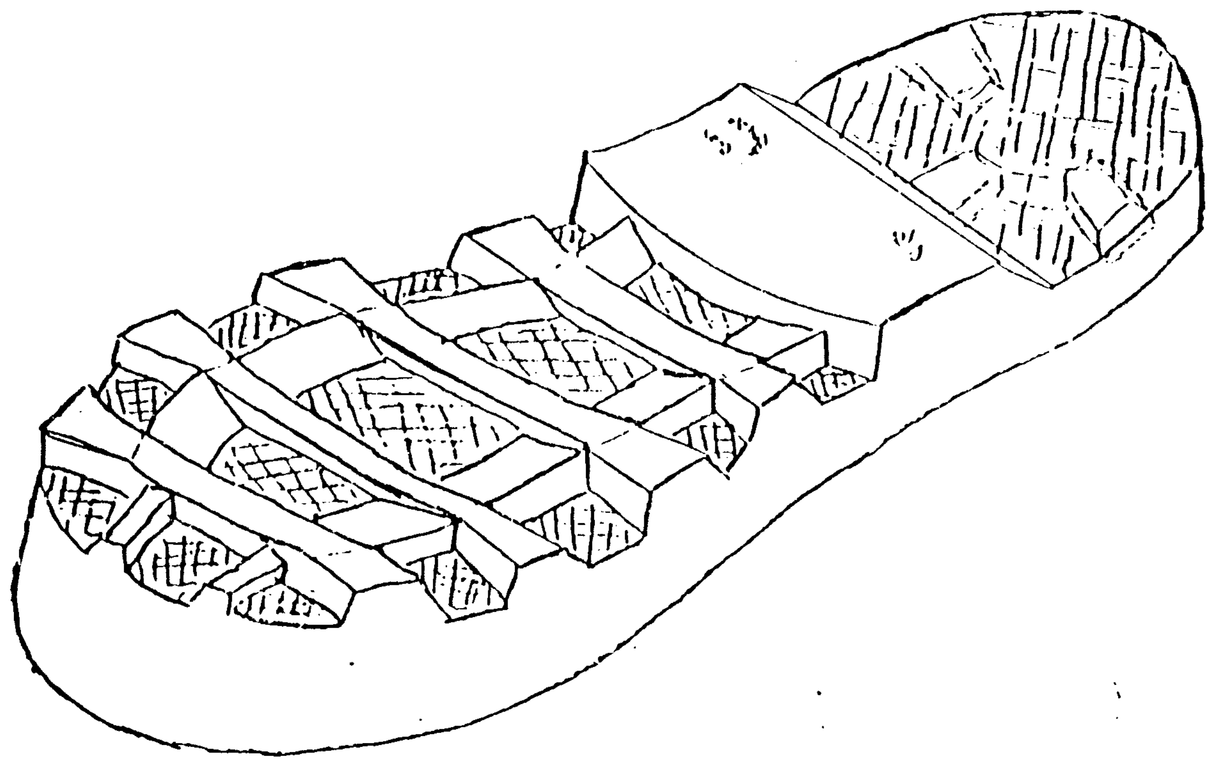


Figure 2. Mold Soleplate design.

TABLE 3

Weight Comparison, Developmental and Present Boots

	WEIGHT PER UNIT	
	Developmental (SBN-88) (g)	Present Combat (g)
Upper after stitching	312	375
Puncture resistant insole *	79	101 (as Hot Weather)
Tacks, nails and staples	0	7
Shank	6	19
Outsole and heel	284	400
Other	52	29
Total	733	931
Chemical resistant bootie	93	

*This element only is compared to the Hot Weather boot. The combat boot insole weighs 65 grams. The total weight, by adjustment of the "other" column, is correct for both boots.

Gore-Tex tape creating an entirely liquid-proof bootie. It is intended that this bootie be worn only when there is some likelihood of exposure to chemical agents. It is secured to the boot with Velcro and quite easily removed for storage and replacement.

Technical bulletin, SAr-1, describing the Winfield Saratoga system of chemical protection, is attached as Appendix B.

5. Puncture Resistance: The upper is made somewhat puncture resistant by the use of the Kevlar/PBI. This gives the fabric panels approximately the same puncture resistance as the leather and so we have managed to retain the puncture resistance comparable to that of the all-leather boot. Ro-Search has increased the puncture resistance of the sole by incorporating three layers of Style 500 Kevlar between a 4-iron leather insole and 3-iron Texon, put together in a similar manner to the puncture-resistant insole of the hot weather boot.

This material was tested for resistance to penetration as required by MIL-B-43154. The average resistance was 207 pounds. This is slightly below the minimum average requirement of 215 for the hot weather boot, but there was no individual reading below 200.

6. Easy Donning and Doffing: The improved speed loop system currently being tested for the regular combat boot has

been used on the SBN-88. Eyelets are substituted for the bottom two rows of loops and the loops are reduced to six pair. The more flexible fabric upper greatly facilitates the operation of the speed loop system.

7. Lightweight Traction Outsole: The outsole is designed for maximum traction and skid resistance. There is a minimum of sharp corners to catch rocks and debris and the natural flexing of the foot tends to keep the cleats clear of such accumulation. By minimizing thicknesses, particularly in the nonwear areas, this design promotes lightweight and lower material cost. See Figure 1 with detail of the design.

8. Increased Foot Health: The full Cambrelle lining provides soft cushiony surface against the foot and, together with the Gore-Tex, provides some insulation against heat and cold. The flexible fabric quarter and gusset allow the upper to take the shape of the foot and leg without an extensive break-in period. The leather portion, reinforced with polyurethane\Surlyn box toe and fiber counter, provides good foot support and protection.

III. Technical Objective Not Met:

Ballistic Resistance: Early investigation led to the conclusion that to attain any appreciable degree of ballistic resistance would require so much bulk, weight and cost as to be impractical for an item of universal wear.

IV. Production Trade-Offs:

1. Kevlar/PBI Quarter and Gusset: This material provides great flame resistance and modest improvement in puncture resistance. However, its abrasive resistance is low compared with either the nylon/cotton duck or Cordura. Is the abrasion good enough to withstand rugged wear? Even though it be determined that the boot wears sufficiently, is the flame resistance and added puncture resistance worth the additional cost?

2. Chemical-Agent-Resistant Bootie: An expensive feature! Is it practical to store and use only in the event of some probability of attack? Conversely, can it be worn comfortably over extended periods? How effective as a chemical agent barrier is the boot without the bootie? Is decontamination practical? Could the Gore-Tex layer and sealed seams be eliminated on the bootie at a considerable savings?

3. Polyurethane/Nitrile Rubber Outsole: Is the flammability of the polyurethane in the exposed area a hazard? Should the outersole be designed so as to reduce the exposed area to a minimum, sacrificing some cost and weight advantage?

4. Puncture Resistant Insole: As explained in Section II, para. 5, the Kevlar insole scored close to the minimum requirement for the Hot Weather boot. However, we have since made other tests on finished boots, which show a less favorable

comparison. It requires 200 pounds pressure for a nail to go through the outsole and insole of the Hot Weather boot. It took nearly 120 pounds to get the nail through our SBN-88. It requires about 70 pounds for total peretration of the present combat boot. Thus, Ro-Search has produced a considerable improvement but the boot is not what it should be, particularly when the additional cost is considered. Ro-Search feels that with additional time it can find other material that will give the needed resistance and still maintain flexibility and light weight.

V. Future Design Changes:

1. Boot Tread and Toe Spring: Unforeseen shrinkage of the materials gives far too much toe spring. This excess will need to be corrected for future production through modification of the profile of the MIL-5 last and the matching mold and foot form.

2. Bootie Lining: Use of the nylon and cotton jersey was a make-shift to overcome a problem encountered of the bootie sticking to the sock and coming out with the foot. For future production Winfield Saratoga has committed to supply a specially developed combination of shoe lining/carbon spheres and cotton jersey.

3. Tread Sole Design: The tread sole must be redesigned to allow more space from the ball of the foot forward for polyurethane to flow. On our prototypes the Texon(R) portion of the

insole was reduced by approximately 1-1/2 irons in the area in order to make sufficient room for the polyurethane. The improved mold design will eliminate the need for this operation.

4. Heel Seat Lasting: The prototypes were cemented by hand and combination hand/machine lasted. As a result, the counter and heel seat are not lasted as tightly as they should be. A special flanged counter must be developed and full machine cement lasting be used on future production.

VI. Conclusions: Except for the ballistics resistance, Ro-Search has generally met the objectives of the contract and feels a very good item has resulted, worthy of further development, testing and eventual adoption.

VII. Recommendations: Phase II should require the production of a quantity of boots in a limited size range for testing for practicality and function. Particular attention in this stage should be paid to the concerns raised in section IV as well as additional ones that are sure to come from the Natick evaluation of Phase I.

This document reports research undertaken at the US Army Natick Research, Development and Engineering Center and had been assigned No. NATICK/TR-99/005 in the series of reports approved for publication.

APPENDIX A

CELANESE PBI

CELANESE PBI

POLYBENZIMIDAZOLE
HIGH-PERFORMANCE FIBER

INTRODUCTION

Celanese® PBI, a polybenzimidazole, is an organic fiber with a unique combination of high-performance properties:

- ☐ Does not burn in air.
- ☐ Does not melt or drip.
- ☐ Retains dimensional stability at high temperatures.
- ☐ Retains significant strength after thermal exposure
- ☐ Retains flexibility without embrittlement, even when exposed to flame or extreme heat.
- ☐ Emits little smoke under extreme conditions.
- ☐ Has excellent thermal stability.
- ☐ Provides excellent garment comfort due to high moisture regain and low modulus
- ☐ Has excellent resistance to chemicals, solvents, fuels, and steam.
- ☐ Resists oils and stains.
- ☐ Has good insulative properties.
- ☐ Is an alternative to asbestos.
- ☐ Processes well on standard textile equipment.

Developed initially for the NASA space program, Celanese PBI is now commercially available and is being used in a variety of textile and industrial applications.

FIBER PROPERTIES

FIBER PHYSICAL PROPERTIES

In addition to its unique combination of tensile strength, thermal stability, and chemical resistance, PBI has textile properties that enable it to be easily processed on conventional textile equipment. Fiber physical properties are summarized in Table 1, and a typical stress-strain curve is given in Figure 1. These tensile properties translate into excellent fabric strength and performance. In addition, PBI's high moisture regain and low modulus contribute to comfort; low thermal and flame shrinkage provide excellent fabric dimensional stability and protection from extreme heat.

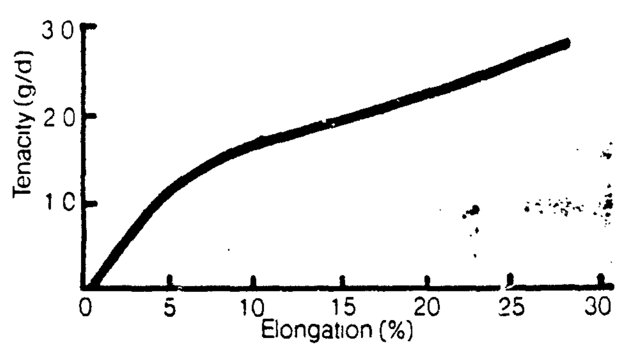
Table 1. PHYSICAL PROPERTIES OF CELANESE PBI STAPLE FIBER

Property	Units	Typical Value
DPF	denier	1.5
	dtex	1.7
Tenacity	g/d	2.7
	dN/tex	2.4
Breaking Elongation	%	28.5
Initial Modulus	g/d	32.0
	dN/tex	28.0
Crimp	per inch	11.0
	per mm	0.4
	%	28.0
Finish	%	0.6
Specific Gravity		1.43
Moisture Regain at 68°F (20°C), 65% RH	%	15.0
Boiling-Water Shrinkage	%	<1.0
Hot-Air Shrinkage at 400°F (205°C)	%	<1.0
Specific Heat	BTU/lb • °F	0.3
Limiting Oxygen Index	%	>41.0
Surface Area Resistivity at 70°F (21°C), 65% RH	ohms/cm²	1 x 10¹⁰
Color		gold
Standard Cut Lengths*	in.	1.5, 2.0, 3.0
	mm	38, 50, 76
Thermal Conductivity	BTU/hr • ft • °F	0.022

*Other cut lengths may be available

Figure 1.

TYPICAL STRESS-STRAIN CURVE



PBI processes well in conventional cotton-system yarn manufacturing. In addition, PBI has been core- and DREF-spun in 100% form or blended with other fibers to create composite yarns with special characteristics. Woven, knitted, needle-punched, and wet- or dry-laid nonwoven fabrics have been produced for a wide variety of industrial and apparel end-uses.

PBI fiber can be blended easily with other flame-resistant or high-performance fibers, including aramids, FR cellulosics, FR wool, glass, or metal fibers. In blends with other high-performance fibers, PBI's excellent thermal resistance and comfort properties can significantly improve fabric performance.

THERMAL PROPERTIES

Flame Resistance

PBI fiber will not burn in air, as demonstrated in conventional flammability tests. Its Limiting Oxygen Index, the lowest concentration of oxygen that will sustain burning of a material, is greater than 41%. Results of ASTM E-84 Flame Tunnel Tests show that PBI is comparable to asbestos in flame resistance, smoke development, and fuel contribution.

Thermal Protective Performance testing (ASTM D-4108, modified for 2.0 cal/cm²•sec. 50/50 radiant/convective heat flux) demonstrates the excellent flame and heat protection of PBI. The Thermal Protective Performance (TPP) values shown in Table 2 are derived by multiplying heat flux by the predicted exposure time in which a wearer of the fabric would sustain a second-degree burn. This test shows that typical single-layer fabrics of PBI are 10-50% more protective than comparably constructed fabrics made of competitive FR fibers.

The Vertical Flammability Test (Table 3) confirms that PBI fiber will not sustain burning and that char lengths are minimal. Fabrics made with PBI will eventually char if exposed to high temperatures at high heat flux for prolonged periods of time. But even after a char has formed, the charred fabrics still retain integrity and flexibility with little shrinkage. Under similar conditions, fabrics of other high-temperature-resistant fibers will shrink, melt, or embrittle. (In contrast, typical apparel fabrics such as untreated cotton and polyester/cotton are completely consumed by flame in the Vertical Flammability Test.)

In U.S. Army laboratory tests (AFML TR-73-28), flight-suit prototypes were evaluated in a pit containing burning JP-4 jet fuel. These tests subjected an instrumented mannequin to a 3-second flame exposure. Sensors measured temperature rise and predicted the extent of skin damage (second and third degree burns) a human wearer would sustain in an exposure equivalent to test conditions. The mannequin wearing a flight suit made with PBI sustained only 2% skin damage. At the same heat flux, mannequins wearing flight suits made with aramid and FR cotton sustained 20% and 34% skin damage, respectively.

In Contact Heat Performance tests, heated steel blocks are placed on a test fabric for 10 seconds at a 1-psi load. In this test, fabrics made from 100% PBI and from a PBI/high-strength aramid blend did not ignite at 1585°F (860°C). Fabrics made of 100% aramid fibers ignited after less than 1 second at 1585°F.

Table 2.
THERMAL PROTECTIVE PERFORMANCE RATINGS OF FABRICS MADE WITH 100% PBI

Weight (oz/yd²)	Fabric Type	TPP RATING*
5	Woven	13.6
6.5	Woven	16.5
7.5	Woven	17.1
5	Knit	13.7
6	Knit	16.0
8	Knit	21.1

*ASTM D-4108 modified for an exposure heat flux of 2.0 cal/cm²•s using a 50/50 convective/radiant heat source. Rating Unit = cal/cm²

Table 3.
PERFORMANCE OF FABRIC MADE WITH PBI IN VERTICAL FLAMMABILITY TESTING (FSTM 191-5903)

Property	Typical Value
After Flame	0 sec
Char Length	0.3 in.

Thermal Stability

PBI has excellent thermal stability and strength retention over a wide range of temperatures and environments. PBI thermal performance is affected by temperature, duration of exposure, and availability of oxygen.

PBI has excellent stability in air and retains most of its strength and integrity after exposure to a variety of severe conditions combining high temperature and duration of exposure. For example, PBI withstands temperatures as high as 1110°F (600°C) for short-term (3-5 sec) exposures. In addition, PBI can withstand temperatures up to 840°F (450°C) for 5-minute exposures, up to 750°F (400°C) for 1 hour exposures, up to 625°F (330°C) for 24 hour

exposures, and up to 570°F (300°C) for 168-hour (1 week) exposures.

As shown in Figure 2, PBI is dimensionally stable at moderate temperatures during extended hot-air exposures. For example, PBI shrinks only 3% in a 24-hour exposure at 600°F (315°C).

Figure 2. THERMAL SHRINKAGE OF PBI FIBER
(Linear shrinkage after 24-hour exposure)

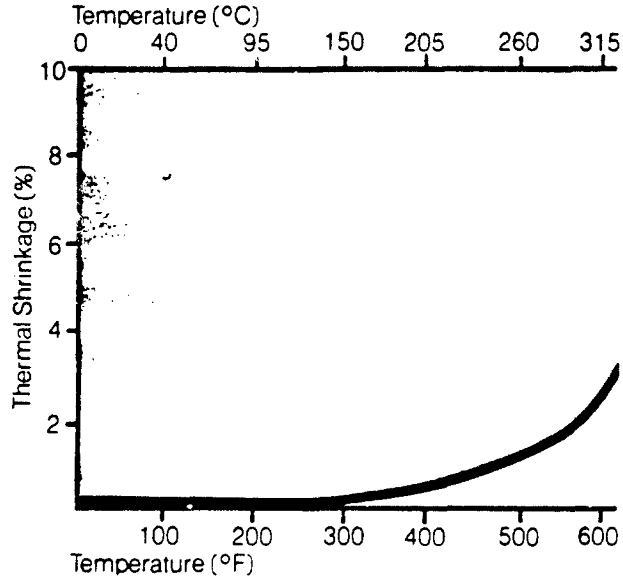
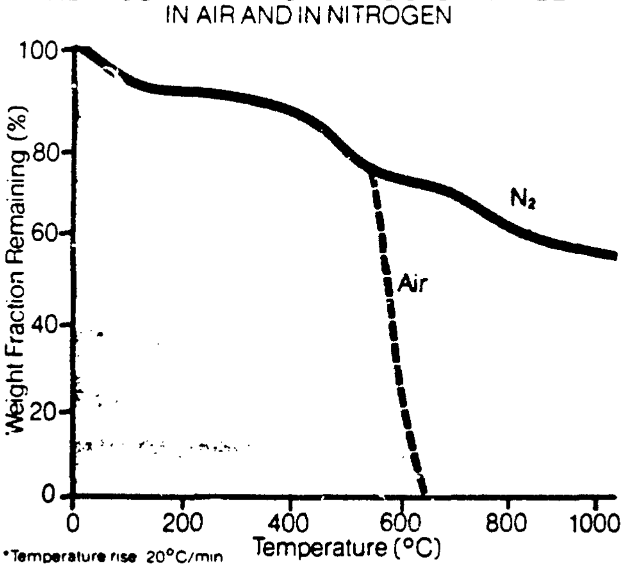


Figure 3.
THERMOGRAVIMETRIC ANALYSIS* OF PBI FIBER IN AIR AND IN NITROGEN



*Temperature rise 20°C/min

In certain high-temperature applications, PBI may be used in environments containing less oxygen than the conditions of the hot-air tests described previously. In low-oxygen environments, PBI has remarkable stability and strength retention after extended exposure to high temperature. When PBI is exposed at 660°F (350°C) under vacuum, there is no change in mechanical properties after 300 hours. Thermogravimetric Analysis (Figure 3) shows that PBI retains integrity up to 840°F (450°C) in air and to over 1830°F (1000°C) in nitrogen.

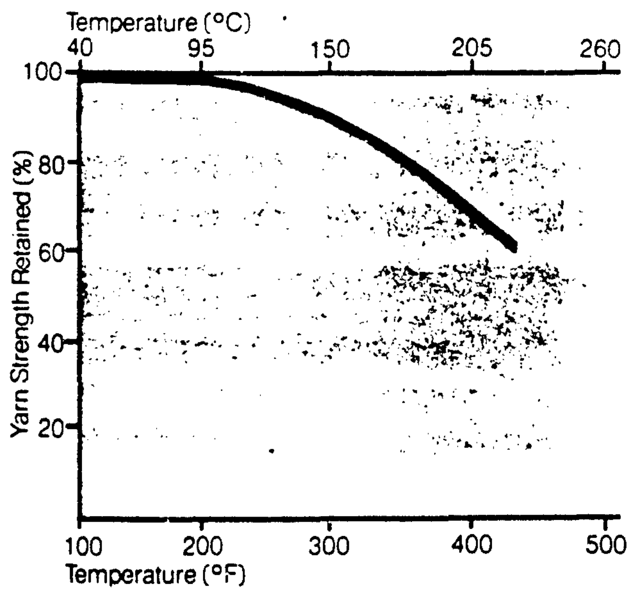
CHEMICAL RESISTANCE

Table 4 shows that PBI fiber has excellent chemical resistance to inorganic acids and bases, even at elevated temperatures. For example, PBI maintains 90% of its strength with up to 24 hrs exposure to 50% sulfuric acid vapors at temperatures as high as 160°F (71°C). Figure 4 illustrates the strength retention of PBI after a 3-hour exposure in 75% sulfuric acid vapors at elevated temperatures.

Table 4.
TENSILE STRENGTH AFTER IMMERSION IN INORGANIC ACIDS AND BASES

Compound	Concentration (%)	Temperature (°F)	Time (hr)	Tensile Strength Retained (%)
Sulfuric Acid	50	85	144	90
Sulfuric Acid	50	160	24	90
Hydrochloric Acid	35	85	144	95
Hydrochloric Acid	10	160	24	90
Nitric Acid	70	85	144	100
Nitric Acid	10	160	48	90
Sodium Hydroxide	10	85	144	95
Sodium Hydroxide	10	200	2	65
Potassium Hydroxide	10	77	24	88

Figure 4.
ACID VAPOR RESISTANCE
(PBI yarn, 3-hour exposure to H_2SO_4, 75% concentration)



PBI fiber maintains its strength when exposed to a broad range of organic chemicals and solvents, as shown in Table 5. In addition, PBI fiber offers excellent resistance to steam hydrolysis. After 72 hours of exposure to steam at 300°F (150°C) and 67 psi (462kPa), fabric made with PBI fiber retains 96% of its original breaking strength.

Table 5.
TENSILE STRENGTH AFTER IMMERSION IN ORGANIC CHEMICALS

Compound	Tensile Strength Retained (%)*
Acetic acid	100
Methanol	100
Perchloroethylene	100
Dimethylacetamide	100
Dimethylformamide	100
Dimethylsulfoxide	100
Kerosine	100
Acetone	100
Gasoline	100

*After exposures at [illegible]

SMOKE & GAS GENERATION

PBI fiber does not burn in air and releases little or no smoke or offgases up to its decomposition temperature. In air, decomposition of PBI typically begins at 840°F (450°C). However, decomposition temperature is affected by duration of exposure and conditions of use. As a result, PBI may remain stable to exposures above 1830°F (1000°C) under certain conditions. As with any high-performance fiber to be used under extreme conditions, each application should be evaluated to insure that products are appropriately engineered for the required level of protection.

Measurements show that PBI generates less smoke than other FR or high-performance fibers. For example, the specific optical smoke density (D_S) of PBI is 2, compared with 36 for FR rayon and 3-8 for aramids. When exposed in air to temperatures below its decomposition point, PBI emits carbon dioxide and water, with traces of sulfur dioxide, hydrogen cyanide, and carbon monoxide. (Comparative testing shows that off-gassing also occurs with most other FR and high-performance fibers.) Above the decomposition point of PBI, local ventilation is recommended. Assistance in evaluating specific applications is available from PBI technical representatives.

ABRASION RESISTANCE

Fabrics made with PBI have good flat- and flex-abrasion resistance. For example, a 6.5 oz/yd² twill fabric of 100% PBI rates a visual 4 (on a scale with 5 highest) after 50 cycles of 280A Emery flat abrasion. A 9.5 oz/yd² PBI twill fabric withstood more than 20,000 cycles of ASTM D-1175 flex abrasion before failure. In this test, fabrics that exceed 10,000 cycles have excellent abrasion resistance.

In addition, PBI combines excellent abrasion resistance with excellent pilling resistance. Its pilling characteristics are similar to cotton, rayon, or low-pilling polyester variants, resulting in an optimum balance of durability properties.

UV RESISTANCE

PBI's actinic degradation properties are comparable to other organic high-performance fibers. Table 6 shows the typical strength retention of PBI fiber after exposure to a Xenon lamp, which simulates an accelerated exposure to direct sunlight.

Table 6.
STRENGTH RETENTION OF FABRIC MADE WITH PBI AFTER ACCELERATED LIGHT EXPOSURE*

Exposure Hours	Tensile Strength Retained (%)
24	70
120	50
192	50

*ASTM 16E 1978

ELECTROSTATIC DISSIPATION

PBI's chemical structure and high moisture regain contribute to excellent static dissipation, as shown in Table 7. PBI fabric surface resistivity is 1000 times lower than aramids. In addition, PBI shows no static cling to nylon fabric at humidities as low as 25% RH.

Table 7.
ELECTRICAL PROPERTIES OF FABRICS MADE WITH PBI

Ambient Conditions	Surface Resistivity (ohms/cm²)	Static Cling (AATCC-115-1977)
68°F, 25% RH	16×10^{10}	0
68°F, 45% RH	5×10^{10}	0
68°F, 60% RH	2×10^{10}	0
68°F, 65% RH	1×10^{10}	0

COMFORT

Fabrics made of PBI fiber have soft, natural aesthetics and excellent comfort. Compared with other high-performance fibers, PBI fiber's low modulus and its elongated cross section (Figure 5) are like that of cotton. Both of these factors contribute to the softness and flexibility of fabrics made with PBI. In addition, PBI (with a moisture regain of 15%), is 50% more absorbent than cotton. Gillette Research Institute independently compared the comfort of garments made with PBI to cotton garments and judged PBI comparable to cotton in comfort.

Figure 5.

PBI FIBER CROSS-SECTION

APPLICATIONS

A unique combination of properties makes PBI a candidate for many critical applications. In pure form or in blends with other fibers, PBI contributes outstanding thermal, flame, and chemical resistance while offering desirable garment comfort and textile processibility. PBI has been commercialized in a number of applications and is in the process of being qualified for others.

Following are examples of the applications where PBI is being used:

- Firefighters' protective apparel (turnout coats, sock hoods, and proximity gear.)
- Industrial work apparel.
- High-temperature protective gloves.
- Protective clothing for foundry workers.
- Welders' apparel.
- Braided packings.
- Glass-handling conveyor belts and fabrics.
- Aircraft seat encapsulants.
- Rocket-motor insulation.
- High-temperature filtration.
- High-performance sewing thread.
- Protective gloves for use in cryogenic environments.

From its origin in the NASA space program, PBI has extended its usefulness to encompass a broad spectrum of applications in aerospace, military, industrial and textile products. In all of these fields, PBI's unique combination of thermal performance, chemical resistance, and textile processibility create exciting new options in product design.

For help in meeting the requirements of *your* critical application, please contact:

Celanese Corporation

PBI Business Unit
P.O. Box 32414
Charlotte, NC 28232
Telephone: (704)-554-3487
Telex: 575-141

CELANESE®

APPENDIX B

SARATOGA IN CD PROTECTIVE CLOTHING

AND TEST DATA

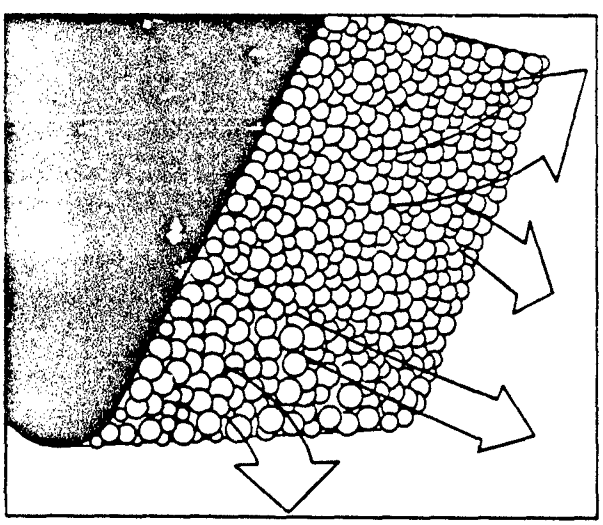
WINFIELD
SARATOGA

TECHNICAL BULLETIN SAr-1
SARATOGA IN CD PROTECTIVE CLOTHING

SARATOGA, an extraordinary filter system possessing enormous adsorption capacity, is available *today* in production quantities to address the military's need for a more durable, comfortable and lightweight uniform for the individual soldier which affords chemical agent and environmental protection.

The development of **SARATOGA** into a highly reliable and excellent replacement for use in chemical defense protective clothing by the German firm of Blucher GMBH, has been ongoing for several years. The system is now available in several different configurations through the United States licensee, Winfield Manufacturing Company. For over twenty-five years, Winfield has been a major supplier of clothing, textiles, and equipage to the military services. The company is the prime manufacturer of the CD protective garment.

The **SARATOGA** system, which uses encapsulated active carbon spheres, has demonstrated lower heat stress, higher air permeability, repeated laundering, resistance to perspiration and petroleum products, non-flammability, good strength, less bulk and excellent agent protection.



Spherical adsorbers bonded to a typical carrier material.

THE SARATOGA SYSTEM

The **SARATOGA** system utilizes spherical adsorbers which, due to their symmetry, have higher strength than any other form of activated carbon. The system is superior because it allows higher quantities of activated carbon per unit area than other filters while offering the best possible flow conditions for adsorption.

During the manufacturing process the outer surface of the sphere becomes extremely hard, but has enough pores to guarantee an excellent access to the softer core ensuring high adsorption efficiency with good wearing properties.

Because of a special treatment of the inner surface of the carbon sphere nitrogen containing groups are formed which bind water only slightly. This special treatment leaves **SARATOGA** practically insensitive to humidity and perspiration and allows repeated washings.

In the **SARATOGA** system, the carrier material is not fixed, thereby permitting optimum adaptation to specific problems by using the appropriate fibers or textile constructions.

The special process of fixing the adsorbers on the carrier fabric guarantees maximum adherence with excellent hydrolytic stability together with good fastness to rubbing abrasion.

As the adhesive covers only a small part of the adsorbers, the high amount of surface area provides for a greater number of impact sights leading to excellent adsorption. This explains why an excellent filter performance exists in spite of the comparatively large "gaps" between the spheres.

PRODUCT EVALUATIONS

Several product evaluations have demonstrated the performance and cost-effectiveness of garments made from **SARATOGA** for individual soldier protection when compared to activated carbon loaded foam systems.

These evaluations have demonstrated that **SARATOGA** is an excellent filter system in five significant areas including chemical agent protection, comfort, launderability, decontamination and regeneration.

TECHNICAL BULLETIN SAr-1 • SARATOGA IN CD PROTECTIVE CLOTHING

CHEMICAL AGENT PROTECTION

According to institutions like Natick R&D Center, Battelle Columbus Laboratories, Munster, TNO and Fraunhofer-Gesellschaft (FHG), SARATOGA demonstrates superior performance in chemical agent protection when compared to existing CD materials.

Fabrics as light as 340gm/m² exhibited greater than 150 hours of HD vapor protection and garments wear tested for as long as 30 days still evidenced greater than 24 hours protection.

COMFORT

The Hohenstein Forschunj Institute found that SARATOGA can be worn for longer periods of time with reduced heat stress.

Biophysical evaluations for determination of thermal insulative (CLO) and water vapor permeability (I_m) indices were conducted with gas mask, hood, gloves, overshoes and steel helmet. Results indicate a dramatic decrease in CLO value (less than 1.65) and a substantial increase in I_m (greater than 0.4). Testing at the United States Air Force/School of Medicine using the treadmill demonstrated reduced weight loss and a higher rate of evaporation when compared to carbon loaded foam systems.

LAUNDERABILITY

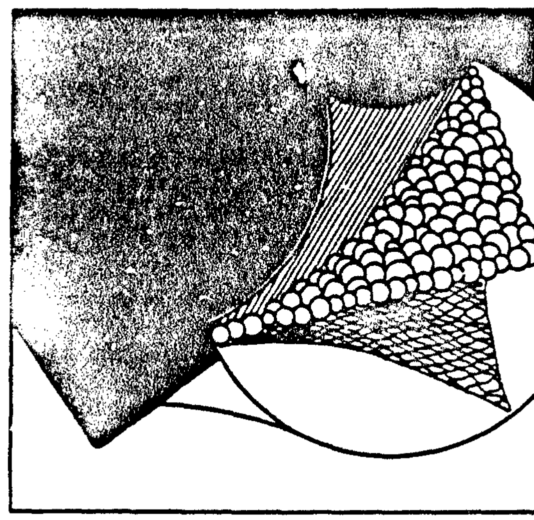
The German Military demonstrated that SARATOGA can withstand multiple launderings without significant loss of agent protection.

Two case studies were conducted, one for 24 hours/day continuous for 7 days and the other for 7 hours/day continuous for 7 days. After each 7-day period the garments were laundered and checked for agent protection. No significant loss in agent protection was evident when compared to new garments.

DECONTAMINATION

TNO, the Netherlands test facility, found that SARATOGA can be decontaminated.

Heat treating in hot air for 1 hour at 165°C reduced retained contaminate levels to a zone where the skin was unaffected. Continued heating for another hour resulted in retained contaminate levels that were not detectable.



Typical garment cross-section illustrating liquid resistant outer layer coupled with spherical adsorbers bonded to a carrier material.

REGENERATION

The German test facility at Munster determined that SARATOGA can be regenerated.

Test garments were loaded with 13gm/m² of HD agent. The garments were subjected to a 1m/sec air stream at 150°C. After 1 hour the residual agent level was measured to be less than 10 per cent of the original loading, and after 2 hours the residual was less than 1 per cent. In addition, the garment regenerated for 1 hour was worn by a test subject for 16 hours with no sign of skin irritation.

For additional information on the use of **SARATOGA** *in chemical defense protective clothing applications, please contact:*

Winfield Manufacturing Company
Suite 6600
Empire State Building
350 Fifth Avenue
New York, N.Y. 10118
Tel. (212-695-2860)

Issued October 1984 by Winfield Manufacturing Company.

02/26/1993

SARATOGA U.S.A., INC
DATA SHEET

FABRIC IDENTIFICATION:

The laminated fabric, **PYJAMA 2**, is composed of an outer shell made from cotton single jersey knit, spherical adsorbers (nominal diameter of 0.4 mm) and a cotton single jersey knit inner liner.

Physical and Chemical Properties

Characteristic	Test Method	Results
Construction		
outer shell	Fed Std 191 - 5041	2.95 oz/yd^2
spherical adsorbers	Fed Std 191 - 5041	2.36 oz/yd^2
inner liner	Fed Std 191 - 5041	2.95 oz/yd^2
Weight	Fed Std 191 - 5041	10.30 oz/yd^2
Breaking Strength	Fed Std 191 - 5100	
machine		>50.0 lbs
transverse		>50.0 lbs
Tear Strength	Fed Std 191 - 5134	
machine		>3.0 lbs
transverse		>3.0 lbs
Air Permeability	Fed Std 191 - 5450	100.0 $ft^3/ft^2/min$
Agent Protection		
mustard (HD)		
vapor vapor	TNO Test Procedures	773 $mg\ min/m^3$

PRINS MAURITS LABORATORIUM (TNO)
CHEMICAL AGENT TEST PROCEDURE
DYNAMIC VAPOR TEST

Vapor Vapor ... *testing the protection of permeable clothing against mustard (HD) gas.*

Test Procedure

A 1.5 cm^2 specimen of complete clothing assembly(1) is positioned in a glass cell and exposed to an air stream of 5 m/s perpendicular to the fabric. The air stream (5400 l/hr) is contaminated with HD vapor in a concentration of 20 mg/m^3. The whole system is at room temperature (20-22°C) and placed in a hood at relative humidity of 30-80 % . Contaminated air is sucked through the test specimen at a speed of 0.3-0.5 cm/s depending on the resistance to air of the complete assembly. Penetrated HD is collected in a bubbler. The organic solvent in the bubbler used to trap the HD vapor is either methylisobuticarbinal (1-2 ml), when the bubbler is exchanged every hour (automatically), or diethylsuccinate (1ml) when only one bubbler is used in 6 hours. The amount of HD vapor collected in the organic solvent is determined either spectrophotometrically by the DB3 method or gas chromatographically with a flame photometric detector.

Test Results

Ct, Dose in 6 Hours (mg min/m^3)

Fabric Type	Value
PYJAMA 2	773 mg min/m^3

(1). MIL-C-44031B, NYCO Twill, 7.5 oz/yd^2, quarpel treated was used as a shell and placed overtop of PYJAMA 2. PYJAMA 2 was evaluated as a bipack configuration.

DISTRIBUTION

	Copies
Project Manager, Clothing and Individual Equipment ATTN: AMCPM-CIE P.O. Box 4206 Woodbridge, VA 22194-4206	1
Commander Headquarter U.S. Army Training and Doctrine Command ATTN: ATCD-SE Ft. Monroe, VA 23651	1
Commander U.S. Army Troop Support Command ATTN: AMSTR-E St. Louis, MO 63120	1
Commandant U.S. Army Infantry School ATTN: ATSH-CD-MLS-C Ft. Benning, GA 31905	2
Commandant U.S. Army Chemical School ATTN: ATZN-CM-CS Ft. McClellan, AL 36205	1
Commander U.S. Army Test & Evaluation Command ATTN: AMSTE-TA-T Aberdeen Proving Ground, MD 21005-5055	1
Commander Navy Clothing and Textile Research Facility 21 Strathmore Rd Natick, MA 01760	1
Commanding General MCDEC ATTN: M-30500-CSM Quantico, VA 22134	1
Headquarters Wright Patterson Air Force Base ATTN: ASD-AESD WPAFB, OH 45433	1
Commander U.S. Army Natick RD&E Center ATTN: STRNC-IUC Kansas St Natick, MA 01760-5019	50
RoSearch Inc. North Pine Street Hazelwood, NC 28738	24